Roman STRACHOWSKI, Jan MONIETA
Maritime University of Szczecin

THE IDENTIFICATION OF THE TYPES OF THE DAMAGES IN THE PISTON-CYLINDER LINER SYSTEM OF MARINE COMBUSTION ENGINES

Key words

Marine engine, piston-cylinder liner system, tribological processes, damage, wear.

Summary

This paper presents the results of operational research into the piston-cylinder liner system of marine combustion engines used for ship propulsion. According to research, there has been the identification of damages of the following elements: piston, piston rings, and the cylinder liner unit. In this article, there also has been made an effort to specify favourable conditions for the appearance of individual wear type.

Introduction

The main engine undergoes continuous damages during operation. It is the result of strain ageing and unexpected operational occurrences. For these reasons, there are introduced constructional changes, better lubricating substances and other ways of delivery of oil dose in accordance with engine load. In spite of that, elements of the piston-cylinder liner unit wear during their use.

1. Piston-cylinder liner system

The piston-cylinder liner unit is a kinematic pair, which determines, to a large extant, the economical performance and reliability of the engine. It contains a space where air-fuel mixture is burnt and, then firing, the load is turned into the reciprocating motion of the piston. The heat load contributes to the very difficult running conditions of above-mentioned kinematic pair. The incomplete burning causes the quicker formation of abradant (the soot, ash), settling down on the surface of co-operating elements. It, along with mechanical burden, may lead to the engine's incapacity for work.

The piston-cylinder liner units of 3 engines of the MAN B&W type 6S46MC-C with power output 7860 kW and 3 engines of the Sulzer type 6RTA58 were subjected with a power output of 9680 kW for operational research. Common feature of these machines was their operation during variable external conditions.

2. Classification of damages of piston-cylinder liner system

Damages to engine elements may be the result of taking under consideration the wrong computational data, the wrong material selection, production defects, of the disturbance of operational principles, e.g. the using of excessive load or not obeying conditions of maintenance service. Natural tribological wear is a process formed as a result of friction. Remaining wear processes arise under the influence of the surrounding environment.

The intensity of wear processes depends on the quality of co-operating elements, their load and influences of environment. The most common damages of mechanical objects may be classified as gradual damages (material consumption) and unexpected sudden damages.

Gradual damages are damages that can be foreseen on the basis of maintenance service or overhaul. These damages are connected directly with tribological wear processes.

Sudden damages are damages that are difficult to foresee based on maintenance service or overhaul. Cracks, volumetric deformations, or overall object destruction may be the result of mechanical overload, impact, or explosion.

2.1. Gradual damages of kinematic pairs

Abrasive wear is a wear of rubbing surfaces as a result of an elementary mechanical processes such as ploughing, micro-slicing, scratching, ridging, shearing, or the detaching of protrusions of superficial irregularities [2]. This process is caused by hard particles of impurities sliding between co-operating surfaces of the kinematic pair or by conical asperities of these elements, which worked earlier. Colloidal particles, metallic particles, oxides, carbides, particles of sulfides and phosphides are an abradant. The discussed type of wear is the most common cause of piston skirt (Fig. 1) of the main engine S46MC-C.

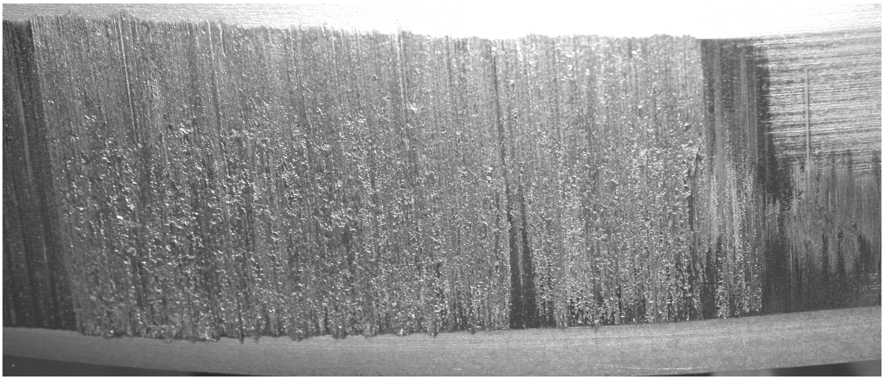

Fig. 1. Abrasive wear of piston skirt

Abrasive wear may be a purely mechanical process. It may also be a partly chemical and partly mechanical process, which is observable only in thin superficial layer intensifying oxidative wear. Moderated parameters of friction and the large roughness of co-operating surfaces are favourable conditions for abrasive wear. Additionally, the size and the concentration of abradant in the lubricating oil determine the intensity of the wear. The abrasive wear of a cylinder liner is shown in Fig. 2.

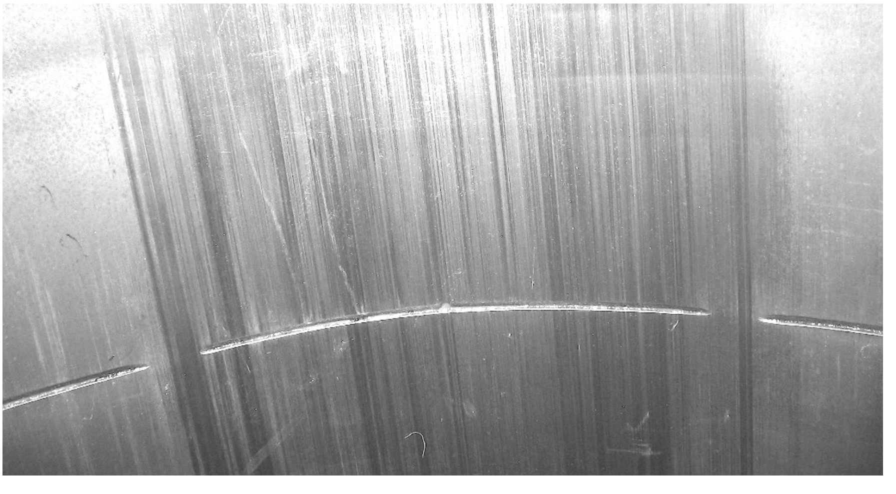

Fig. 2. Abrasive wear of cylinder liner

The general form of the function describing abrasive wear is as follows [4]:

$$J_t = \frac{W_S}{S} = f\left(P, U, H_m, H_s, r, D, C_s, C_w\right) \quad (1)$$

where:

- S – friction way,
- P – external load,
- U – sliding speed,
- H_S – softer material hardness of kinematic pair,
- H_A – abradant hardness,
- r – radius of frictional particle seated in material of kinematic pair,
- D – diameter of free frictional particle,
- C_s, C_w – concentration of abradant and water.

Adhesive wear is a wear of the rubbing surfaces as a result of adhesive connections, which are disrupted during the sliding of co-operating elements against each other [2]. This type of wear is due to dry friction as well as semi-dry and boundary friction during starting and stopping of the main engine. It is one of the fundamental types of cylinder liner wear (Fig. 3).

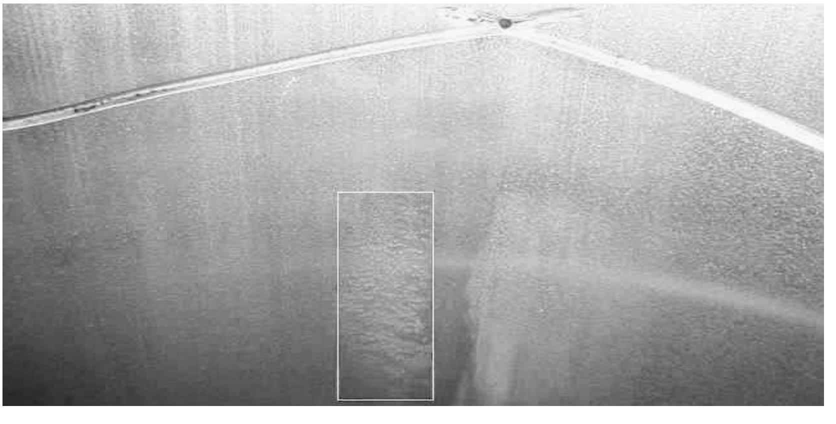

Fig. 3. Adhesive wear of cylinder liner

The general form of the function describing adhesive wear is as follows [4]:

$$J_a = \frac{W_A}{S} = f\left(P, U, T_{ol}, \mu, M, V_m, E_o, t_0, H, \lambda_1, \lambda_2\right) \quad (2)$$

where:

S, P, U – like in formula 1,
T_{ol} – temperature of lubricant in the beginning of kinematic pair,
μ – coefficient of friction,
M – the molecular weight of lubricant,
V_m – molar volume,
E_c – heat of absorption of lubricant on lubricating surface,
t_0 – basic period of molecular vibration of lubricant in absorbed state,
H – hardness of frictional surface,
λ_1, λ_2 – thermal conductivity of materials of frictional surfaces.

Two co-operating surfaces may be brought together in contact when there is an insufficient thickness of the convergent lubricating film. The local pressure at relatively few asperities becomes extremely high as a normal pressure is applied. However, relative motion in the interaction area disperses the contaminated oil wedge in the contact points, increasing possibilities for cold welding of junctions. The continued movement of elements against each other causes the shearing of junctions and the forming of new ones. The friction surface undergoes irregular changes in the described tribological process.

Scuffing is the wear of rubbing surfaces as a result of the total influence of abrasive wear and adhesive wear. Figure 4 is an example.

Fig. 4. Scuffing of cylinder liner

Fretting is the tribological wear of rubbing surfaces as a result of their relative oscillatory motion about low amplitude and the cyclic effect of the mechanical load as well as oxidation [2]. There is abrasive and corrosive wear.

Micro-displacements of co-operating elements are common during operation. They cause that some ranges high-energy turn into heat. There is a metallic junction formed when mass decrements are high. It is quickly crystallised and, in the aftermath of changes, acts as an abrasive. Basically fretting is a form of adhesive wear. Burden causes the adhesion of asperities. Then vibration causes their disruption [1]. Most commonly, fretting is combined with corrosion. The product corrosion is oxide and fine reddish-brown powder. The oxide particles are abrasive and are not displaced very far because of the closeness of surfaces. Further oscillatory motion causes alternated abrasion and oxidation. This type of wear can cause the formation of material stresses and results in fatigue cracks and finally the complete failure of the kinematic pair.

Fatigue wear is the wear of rubbing elements as a result of material fatigue in the zone of top layer caused by the cyclic effect of mechanical load at points of contact [2]. This wear takes place in the piston-cylinder liner system where there is sliding contact of co-operating elements, as well as in other kinematic pairs with rolling contact of their elements. Piston rings and piston ring grooves are mainly subjected to this type of wear.

Despite the fact that surfaces do not touch each other directly, the oil film is used for transferring high stresses. Changes in the top layer are not formed when mass decrements are caused by adhesive or abrasive wear.

There are changes in stress conditions that arise from fatigue cracks and mass decrements. Local stress pile-ups are accumulated as a result of stroke, overheating, and the local corrosive cluster. The mass decrements occur after exceeding the critical number of stress cycles.

Oxidative wear is the wear of rubbing elements as a result of creating and removing of the oxidised top layers of their surfaces [2]. The area near the TDC (top dead centre) of the cylinder liner is a characteristic place where this type of tribological wear is created. It distinguishes itself with a slight mass decrement of rubbing surfaces.

Corrosive wear is a type of gradual damage to the surface as result of the chemical or electrochemical effect of the environment. The corrosive process may also occurred under the simultaneous influence environment and friction, resulting in the above-mentioned abrasive corrosion called fretting.

In the space of the engine combustion chamber, high-temperature and low-temperature corrosion may be found when the second type of wear is related directly to the piston-cylinder liner system. This corrosion is caused by compounds of the oxidising of sulphur reacting with water vapour. The formed sulphuric acid is a substantial threat to total cylinder volume. It is found in piston ring grooves and on cylinder liner surface. Accordingly, the internal surface of the cylinder liner is coated with chrome to prevent undesirable wear. Corrosive wear is shown near the crack in Fig. 6.

The corrosion starts changing the attacked surface and then goes deeper. Sometimes, corrosion products create a layer-preventing element from farther decaying and forming other types of wear. For instance, the oxidised layer and corrosion products counteract the adhesion of asperities.

2.2. Sudden damages of kinematic pairs

Sudden damages are characterised by the independence of the probability of their appearance to the operational time. The cracking and burning of piston rings, as well as cracking of cylinder liners, are the most common results of unexpected damages in the piston-cylinder liner system.

In spite the fact that the highest stresses are in centre or circumference, piston rings do not often break perpendicular to their gaps during operation. This damage is usually caused as a result of the distortion of piston ring grooves, the excessive clearance between the piston and cylinder liner, the clearance gap being too small, or the defective shape of piston rings. While burning of the piston rings (Fig. 5) is a more random case. The process takes place when there is a violent increase in temperature of the rubbing surfaces and a high velocity of fumes during blow-by.

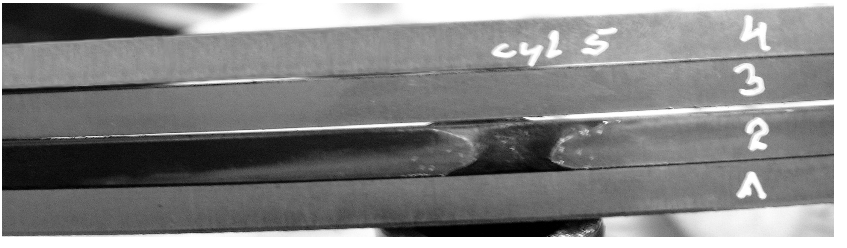

Fig. 5. Burnt part of piston ring

Cylinder liners commonly break as a result of exceeding the permissible mechanical and thermal tensions in the area of the sides of the combustion chamber. Some cylinder liners break in the zone of oil grooves (Fig. 6). In this case, damage occurs after extended work at higher temperatures.

Fig. 6. Crack of the cylinder liner in the area of lubricating grooves

Conclusions

The correct identification of wear lets us undertake proper measures to reduce factors that influence the extent of damage. It seeks better constructional solutions in new model engines or to find a suitable replacement part during a overhaul [3]. Simultaneously, engine room personnel should be aware of the need to introduce changes in the maintenance of the main engine. For instance, oil dose delivered to the engine should be under control. Very often there are slight changes, but necessary for proper operation of the ship's propulsion.

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Reviewer:
Zdzisław CHŁOPEK

Identyfikacja rodzajów uszkodzeń systemu tłokowo-cylindrowego okrętowych silników spalinowych

Słowa kluczowe

Silniki okrętowe, system tłokowo-cylindrowy, procesy tribologiczne, uszkodzenie, zużycie.

Streszczenie

W pracy przedstawiono wyniki badań eksploatacyjnych systemu tłokowo-cylindrowego okrętowych silników spalinowych zastosowanych jako napęd główny statku. Na podstawie zebranych informacji dokonano identyfikacji uszkodzeń elementów tłok–pierścienie tłokowe–tuleja cylindrowa. W artykule tym podjęto również próbę określenia warunków sprzyjających występowaniu danego rodzaju zużycia.